at five years although a slight increase in CMC1 scores was observed. Patterns of involvement were also similar as witnessed by high intra-class coefficients for DIP (0.88), PIP (0.79), CMC (0.73) and aggregate scores (0.87) at five years. On side by side comparison of photographs, 4 subjects (2.8%) had probable worsening and 4 had (2.8%) definite worsening in the IP joints, and in the CMC1 joints 14 (9.8%) had probable and 10 (7.0%) definite worsening. Progress in the CMC1 joints was more apparent in females.

Conclusions: At this age, there is little change in IP joint osteoarthritis and photographic scores do not detect changes after 5 years, although side by side comparison detects occasional worsening. There appears to be more progress of HOA in the CMC1 joints in this age group, but hand position in photographs is very important in estimating OA in these joints and changes in hand posture due to aging and other neuromuscular conditions may exaggerate apparent worsening.

This study confirms the robustness of the photographic method showing high reproducibility at five year intervals. Even in this age group, progress of HOA can be determined on side by side comparison of photographs.

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LOAD RESPONSE OF KNEE CARTILAGE T2 IN PATIENTS WITH MENISCUS DISORDER: EVALUATION USING LOADING IN SITU MRI

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Purpose: The normal meniscus was assumed to distribute the load transmission over the entire surface of the articular cartilage, and meniscus disorder may lead to abnormal load distribution in response to load-bearing, resulting in high prevalence of osteoarthritis progression. Therefore, evaluation of intra-articular biomechanical condition after meniscus injury is important to estimate risk of subsequent progression of osteoarthritis and to decide appropriate treatment methods. Recent studies showed that responsiveness of articular cartilage to compressive loading by T2 value may indicate pressure distribution on the cartilage, via evaluation of dynamic changes in the collagenous architecture or water influx or efflux. We have developed a loading apparatus to apply axial load to the knee joint during MR imaging in order to simulate physiological load-bearing condition while standing. Our objectives were to examine clinical feasibility of cartilage T2 with use of loading in situ MR imaging, for evaluation of abnormal pressure distribution in patients with knee meniscus disorder.

Methods: Thirteen patients with knee injuries (13 knees) and 10 asymptomatic normal volunteers (10 knees) were imaged on a 3.0 T GE MRI scanner using a 8-channel knee phased array coil. The mean age of the patients and volunteers were 34 and 32years, respectively. Among 13 patients, 9 patients had either or both of the medial and lateral meniscus abnormalities and the other 4 patients had ACL or PCL injury without meniscus disorder, which were confirmed by arthroscopy. During MR imaging, the participants was laid on a custom-made loading apparatus, which had a pulley system linked to a sliding foot plate. The shoulders of the participants were strapped tightly, and 50% of the body weight was applied via the foot plate, when loading. On unloading and loading conditions, sagittal T2 maps of the medial and lateral femoro-tibial joints were obtained from multi-echo spin echo sequence with fat-suppression (TR, 1500 ms; 8 echoes between 10.0 ms and 80.0 ms; field of view, 12 cm; matrix, 384×256). On each of medial and lateral mid-sagittal image, the cartilages at the weight-bearing ranging anterior and posterior margins of the meniscus were divided into 3 sections with equal length, and each section was further divided into deep and superficial layers with equal thickness, using a custom-made software (Fig. 1). Change of T2 values by loading in each ROI was compared between patients and normal volunteers, and between joint compartments with and without meniscus tear among patients, using the nonparametric Mann-Whitney U test.

Results: On unloading condition, there was no significant difference of T2 at each ROI between patients and volunteers, except AD of the medial femoral cartilage in which T2 of the patients was significantly higher ($p=0.01$). By loading, T2 was likely to decease at each zone, however, there was no significant difference of T2 change at each ROI between patients and volunteers. Among 13 patients, meniscus tear was noted in 5 knees at the medial side and in 7 knees at the lateral side. In the medial side, T2 at AS of the femoral and tibial cartilages decreased significantly larger in knees without meniscus tear than knees with meniscus tear (Femoral cartilage: -13.3% vs -0.3%, $p<0.05$; Tibial cartilage: -8.2% vs +4.7%, $p<0.05$)

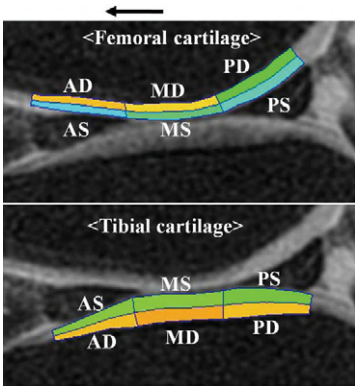

Figure 1. Definition of ROIs at the femoral and tibial cartilage.

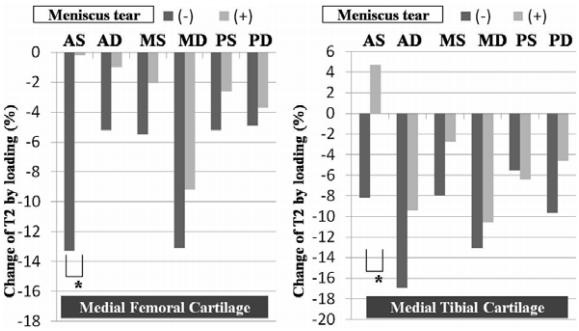

Figure 2. T2 change by loading in knees with and without meniscus disorder (*$p<0.05$).

(Fig 2). In the lateral side, there was no significant difference of T2 decease between knees with and without meniscus tear.

Conclusions: Significantly smaller decrease of T2 in knees with meniscus tear may reflect location-specific load transmission failure associated with the meniscus tear. In this context, T2 evaluation under loading conditions can be expected to provide biomechanical assessment of pathological conditions with respect to localized stress concentration in the cartilage of patients with knee injuries.

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THE NATURAL HISTORY OF OA ASSOCIATED BMLS IN THE OAI PROGRESSOR COHORT

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Purpose: The natural history of osteoarthritis (OA) related bone marrow lesions (BML) is poorly understood. Although it is clear that BMLs are not static, studies have reported conflicting results concerning their turnover and location. Semi-quantitative evaluation has been unable to study the spatial and temporal distribution of BMLs. This study employed a novel statistical model to precisely locate the BMLs within the subchondral bone and generate detailed anatomically relevant maps to track their change in size over time.

Methods: A cohort of 88 subjects was generated from the Osteoarthritis Initiative (OAI) progression groups 0.B.1 (baseline) and 1.B.1 (12-month follow up visit). Subjects had K-L scores of 2 or 3; medial JSN > lateral JSN, medial osteophytes and ≥1° of varus mal-alignment. OA related BMLs were defined as ill-delineated regions of hyperintensity in the subchondral bone, excluding the region adjacent to ligament attachment sites on Turbo Spin Echo magnetic resonance images (MRIs). The slice-by-slice, subvoxel delineation of the lesions across the paired images was blinded to time-point but not to subject using EndPoint software (Imorphics, Manchester, UK). Study reproducibility was determined using a Bland Altman test and the measurement error defined as the smallest detectable difference (95% level of agreement). BML depth with respect to the adjacent bone surface was calculated using an adapted method previously utilised for articular cartilage thickness measurement. A statistical bone model was

fitted to each image across the cohort, creating a dense set of anatomically corresponded points on the femur, tibia and patella. Parallel, slice-by-slice segmentations were converted into surfaces to calculate BML volume, while BML depth and position was obtained by recording the number of BML voxels traversed along a 15 mm normal to the bone surface.

Results: 81 of the 88 subjects were included in this study, with 7 subjects excluded due to image quality or absence. At baseline 75 subjects (93%) had BMLs present in $\geq$ 1 compartment. The majority of lesions were observed in medial compartments (53.7%) compared to lateral compartments (25.5%) and the patella (20.7%). Of the 188 compartments with BMLs 86 (46%) demonstrated change greater than the SDD, which was calculated as 727 mm^3 (around 9 cubic millimetres). Fifty (26.6%) compartments exhibited an increase in total BML volume greater than SDD at 12 months, while 36 (19.1%) showed decrease in BML volume greater than SDD at 12 months. The average absolute volumetric change in the 86 compartments was 2956.45 mm^3 (S.D 2728.05 mm^3). OA associated lesions were predominantly found in the patello-femoral joint both medially and laterally, and in the medial femoro-tibial joint, as indicated by the average distribution of BMLs across the cohort of 81 subjects.

Table 1: Overview of compartments which contain BMLs at baseline, and compartmental change at 12 months.

	All	MF	LF	LT	MT	PAT
Compartments with BML at baseline (%)	188 (46)	54 (13)	37 (9)	11 (3)	47 (12)	39 (10)
BML volume at baseline mm^3 (SD)	2417.00 (2938.12)	2758.45 (2938.12)	2367.25 (2556.21)	723.53 (607.99)	2627.20 (3179.81)	2215.75 (2938.12)
Compartmental change > SDD (%)	86 (46)	28 (52)	19 (51)	6 (55)	21 (45)	12 (31)
Absolute volumetric change mm^3 (SD)	2956.45 (2728.04)	3301.92 (3587.28)	2049.64 (1214.81)	2650.89 (3106.87)	3307.74 (2650.55)	3124.15 (2074.68)
Increase in volume > SDD (%)	50 (27)	19 (35)	9 (24)	3 (27)	13 (28)	6 (15)
Decrease in volume > SDD (%)	36 (19)	9 (17)	10 (27)	3 (27)	8 (17)	6 (15)

Key: MF = Medial Femur, LF = Lateral Femur, LT = Lateral Tibia, MT = Medial Tibia, PAT = Patella

Conclusions: BMLs are a highly variable feature in subjects with OA, exhibiting a more dynamic development and regression process than previous reports have shown. This study has demonstrated change greater than measurement error in 46% of compartments via the application of a novel methodology.

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THE SPATIAL DISTRIBUTION OF CARTILAGE MR T2 IN A SUBSET OF THE INCIDENCE AND CONTROL COHORTS OF THE OSTEOARTHRITIS INITIATIVE

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Purpose: The Osteoarthritis Initiative (OAI) is a multi-center, longitudinal study aimed at assessing biomarkers in osteoarthritis (OA) including those derived from magnetic resonance (MR) imaging. The purpose of this study is to compare the spatial distribution of cartilage MR T_2 between a subset of patients from the control and incidence cohorts of the OAI, using grey level co-occurrence matrix (GLCM) texture parameters.

Methods: Equal sized (n=57) samples of subjects from the incidence and control cohorts of the OAI were included in this study based on the following inclusion criteria: (1) age range 45-55 years (2) body mass index (BMI) of 19-27 kg/m^2 and (3) Western Ontario and McMaster University (WOMAC) pain score of zero at the time of magnetic resonance (MR) imaging. Subjects from the incidence cohort did not have symptomatic knee OA, but had risk factors for OA, such as knee surgery or previous injury. Subjects from the control cohort had neither knee symptoms nor risk factors for OA. MR sagittal 2D MSME (TR = 2700 ms, TE_1-TE_7 = 10-70 ms) images were used to calculate T_2 relaxation time using 6 echoes (TE = 20-70) and 3 parameter fittings accounting for noise. Articular cartilage was segmented into four compartments: medial/lateral femur/tibia. Mean cartilage T_2 as well as a GLCM (which quantifies the spatial distribution of cartilage T_2 values), were calculated for each compartment. GLCM texture parameters including entropy, contrast, and angular second moment (ASM) were calculated at 0 degrees (corresponding to the anterior-posterior axis), 45 degrees, 90 degrees (corresponding to the superior-inferior axis), and at 135 degrees, with 1 pixel offset. Differences in cartilage mean cartilage T_2 and GLCM texture parameters were assessed between control and incidence groups using regression models adjusted for BMI and age.

Results: Subjects from the incidence cohort had significantly ($p < 0.05$) elevated mean cartilage T_2 (medial femur, medial tibia), elevated GLCM-contrast (medial tibia), elevated GLCM-entropy (medial femur), and decreased GLCM-ASM (medial femur), compared to control subjects. Of all compartments, mean T_2 was greatest in the medial femur (mean T_2 incidence cohort = 37.74±2.28 ms, mean T_2 control cohort = 36.90±2.18 ms) and lowest in the lateral tibia (mean T_2 incidence cohort = 28.20±1.75 ms, mean T_2 control cohort = 28.08±1.83 ms).

Conclusions: This study evaluated mean T_2 values as well as the spatial distribution of cartilage T_2 using GLCM texture analysis. The results indicate that both mean and spatial distribution of cartilage T_2 values differ between subjects in the incidence and controls cohorts of the OAI, in particular in the medial femoral condyle. Subjects at risk for OA not only have elevated mean T_2, but also have a more heterogeneous distribution of T_2 pixel values. While both subject cohorts were asymptomatic, their cartilage biochemical compositions (as assessed by cartilage T_2 parameters) differed. These results suggest that GLCM texture analysis supplements the standard measurements of mean T_2 and may aid in the detection of early OA.

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SEGMENTATION AND ANALYSIS OF IN-VIVO CONTRAST ENHANCED MICROCT DATA: A NOVEL METHODOLOGY FOR OPTIMAL QUANTIFICATION OF CARTILAGE DEGENERATION

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Purpose: Similar to in delayed gadolinium enhanced magnetic resonance imaging (dGEMRIC) it is possible to image cartilage and determine its glycosaminoglycan (GAG) content with contrast-enhanced μCT (CECT). In order to analyse cartilage scans, accurate thresholding is necessary for correct structural representation of the tissue.

The first goal of the current study was, to investigate how in a single micro-CT scan both quantity and quality of cartilage can be optimally assessed in rat experiments. Second, we used the best analysis method to measure cartilage changes over time in two different osteoarthritis (OA) animal models: the mono-iodoacetate (MIA) model characterized by GAG leakage and the groove model that is induced by cutting a small groove in the trochlear cartilage and characterized by collagen matrix damage.

Methods: In the first experiment, male Wistar rats (n = 6) were injected in one knee with 1mg of mono-iodoacetate (MIA), the contralateral knee joint received a saline injection and functioned as a control. After one week, all knees were CECT scanned and all patellas harvested for an ex-vivo scan (golden standard). For this scan, the patellar cartilage was saturated in a 40% ioxaglate contrast solution until an equilibrium state was reached. All *in-vivo* CECT scans were analysed using three different global thresholds and one local thresholds segmentation method. Outcome measurements using these segmentation settings were compared for their structural representation with the ex-vivo golden standard.

The most optimal segmentation method from this first experiment was used to monitor cartilage degradation in the second experiment. A second group of Wistar rats (n=6) received a 300 μg MIA intra-articular injection and contralateral a saline control. The trochlear cartilage of a third group of male Wistar rats (n=6) were surgically grooved via a minimal invasive procedure through the patellar tendon. All animals were CECT scanned before OA-induction (t=0) and at t=1, 3, 6, 12, 18, 24 weeks after induction.

Results: Cartilage quantity was best measured in datasets generated with *local* thresholds (Figure 1). *Global* thresholds resulted in large differences in cartilage quantity and the measurement error strongly depended on the selected threshold level. Applying the local threshold method resulted

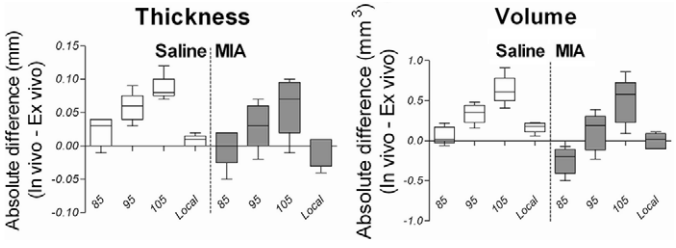

Figure 1